Project 092 Advanced Two-stage Turbine Rig Development

The Pennsylvania State University

Project Lead Investigator

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University Participants

The Pennsylvania State University (Penn State)

- P.I.: Dr. Karen Thole
- FAA Award Number: 13-C-AJFE-PSU-104
- Period of Performance: January 1, 2023 to December 31, 2023
- Tasks:
    1. Architecture/civil design of the expansion (cost-sharing scope)
    2. Electrical design of the new rig
    3. Noise Study
    4. Mechanical design
    5. Procurement
    6. Construction

Project Funding Level

For the 1-year effort, the ASCENT funding was $1,100,000, and matching funds of $1,225,000 were provided by Pratt & Whitney and Penn State.

Investigation Team

Prof. Karen A. Thole (P.I.), management, reporting, and oversight of all technical tasks
Scott Fishbone (project manager and research engineer), Tasks 1-6
Assoc. Res. Prof. Michael Barringer (research advisor), Tasks 1-6
Assoc. Res. Prof. Reid Berdanier (research advisor), Tasks 1-6
Justin Brumberg (research engineer), Tasks 1-6
Jeremiah Bunch (engineering technician), Tasks 1-6

Project Overview

This project will significantly advance the efficiency levels of small-core gas turbines relevant to current engines, as well as future propulsion architectures such as hybrid electric propulsion systems for large single- and twin-aisle aircraft. The motivation for this research is aimed at reducing the carbon footprint of aviation through increasing turbine thermal efficiency, while maintaining or even improving component durability. This project will expand the infrastructure and research scope of the Steady Thermal Aero Research Turbine (START) Lab at Penn State, in which a two-stage, small-core, test turbine will be designed, manufactured, commissioned, and put to use in acquiring the necessary data to meet the proposed goal. The new infrastructure will be referred to as START^{+}. The proposed expansion will result in a research

turbine facility like no other in the world, and will situate turbine research in the United States at the leading edge in efficiency improvement and emissions reduction for future propulsion applications.

Task 1 – Architecture/Civil Design of the Expansion (Cost-Sharing Scope)

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Objectives

Architecture/civil design of the expansion will include the new compressors, two-stage turbine rig, and auxiliary equipment. The current building that houses the START Lab is assumed to be expanded to include all new equipment and will be a part of START+. Any building construction expansion to fit the new two-stage rig will be funded by cost-sharing from Penn State and Pratt & Whitney. A Pennsylvania Labor and Industry building permit will be needed to complete this work, and most of the engineering effort will be devoted to ensuring that this permit is obtained.

Research Approach

The research team associated with this effort in the START Lab engaged with Penn State's Office of Physical Plant (OPP) to plan the laboratory expansion. OPP assigned a project manager, Dwayne Rush, to help oversee the project. Working with the START team, OPP crafted a request-for-proposal document including all specifications for the expansion. The contracting method chosen by OPP for the proposal is a design build model. In this model, the firm will oversee both the design of the expansion and the construction.

The request for proposal was publicly posted in February, and six "teams" representing more than 25 companies responded. OPP and START were extremely satisfied with the high interest in the project from the construction industry and reviewed the proposals together. Three firms were selected for in-person interviews on April 3, 2023, including a presentation on the design and answering of any questions. The three firms selected were Whiting-Turner, Alexander, and Barton Malow.

Penn State selected the team of Alexander, Stantec, HRG, and HF Lenz to complete the design build of the project. Their proposal was optimal in terms of technical knowledge, project management, and pricing. The team held a kickoff meeting on April 25, 2023, to review the scope of the project and begin the design. Weekly meetings were held throughout the rest of the period, focusing primarily on the START+ layout and permit requirements. The design began with more than 10 potential layouts (example in Figure 1).

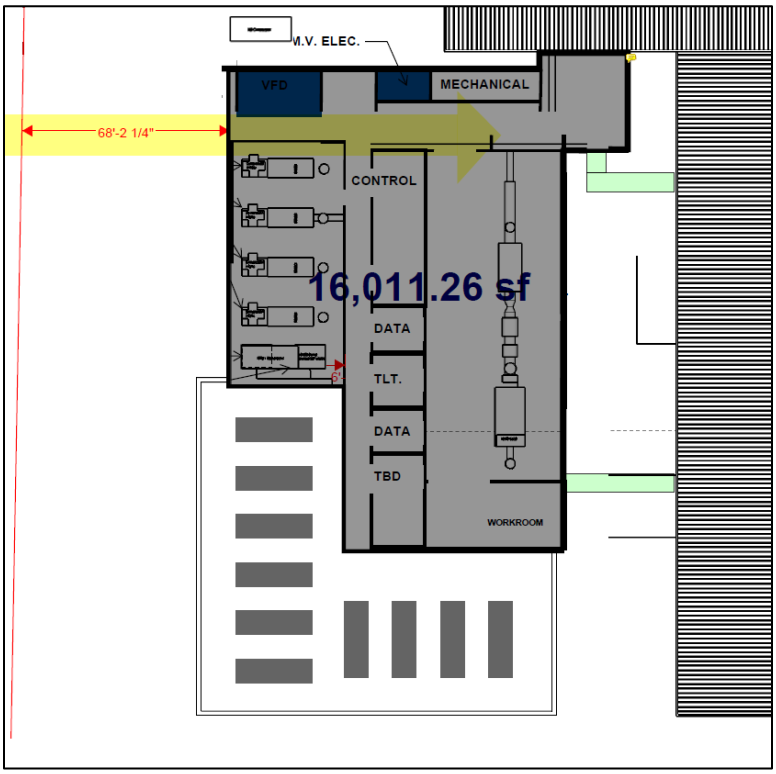

Figure 1. An early START⁺ layout.

As the design began to be refined, the team settled on a turbine flowing from west to east, because this design is the most cost effective, beneficial to the noise output, and optimal for the research. After that design was selected, the team further detailed the design to include the required workspaces, maintenance windows, and code requirements. At the end of June, a detailed layout (Figure 2), was selected to be reviewed by Penn State's architect and OPP for approval. This building is hoped to be a prefabricated metal building that requires such approvals.

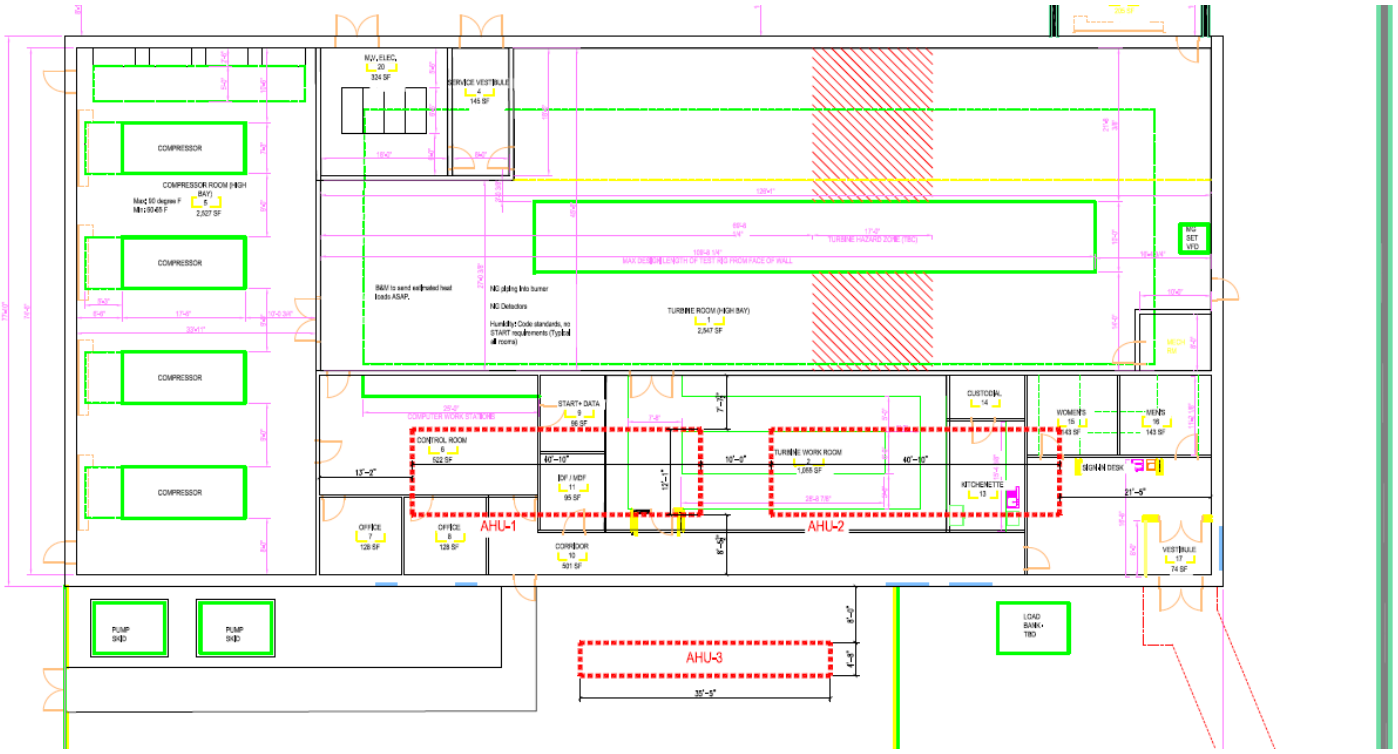

Figure 2. START⁺ detailed layout for Penn State approval.

The building design for START⁺ completed several important milestones in the summer of 2023. Geotechnical test borings were completed and analyzed to ensure that foundations will be designed to the proper soil conditions. In addition, a parking study, as required by the local township, was completed. A township requirement necessitates sufficient parking spaces for the employees of the new facility. The result was positive, indicating that only three parking spaces will be needed to replace those removed for the expansion.

In addition, during the summer, the START team met with various Penn State design leads to ensure that the facility expansion can be exempt from certain standards. These standards include building standards, which are for classrooms, to allow the building to be less expensive. All building codes will still be enforced. In addition, the compressor and turbine rooms will be allowed to operate at higher room temperatures, thereby eliminating the need for air-conditioning in those rooms and enabling savings of millions of dollars. However, the design build team, led by Alexander, continues to estimate a building cost beyond the project's budget. START believes that the elevated cost estimate is because the design is forced to include a traditional-style concrete building instead of a less expensive pre-manufactured metal building. START confirmed with the engineering firm Burns and McDonnell (BMCD) that Alexander's pricing was higher than the national average. Because of Alexander's continued resistance to change their design, which resulted in a much higher price than their initial proposal, along with feedback from Penn State, alternatives are being considered. An option is to not pursue the design build model but instead to pursue the engineering design portion with BMCD and then have Alexander perform the construction.

Task 2 – Electrical Design of the New Rig

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Objectives

The objectives of Task 2 are to complete the electrical design of the expansion to incorporate new compressors, a motor generator, and auxiliary equipment for the two-stage turbine. START⁺ will require more electricity from the local West Penn Power utility, which will be involved in all expansion discussions.

Research Approach

As soon as the program began, Penn State contacted the electrical utility West Penn Power to conduct a power study. The study's goal was to ensure that the START⁺ electrical loads do not impact the local power grid. On May 5, 2023, Penn State received the results. The report concluded that there will not be an impact on the local electrical grid, and only small improvements to a local transformer station will be needed. These updates will cost less than $100,000 and will require a short lead time. In addition, the study concluded that the large air compressors can have "soft" motor starters rather than a more expensive variable frequency drive. These conclusions are extremely positive for the project, and removed a significant risk of the grid being unable to handle the program. The electrical design then proceeded to include a new transformer for START⁺ and a short run of new power lines.

Task 3 – Noise Study

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Objectives

The START Lab, including START⁺, is located in Ferguson Township, which has a noise ordinance that the expansion must meet. The START Lab has an extensive history of understanding and implementing noise mitigation to equipment and will hire a third-party engineering firm to assist with the planning of the expanded facility.

Research Approach

During June 2023, Stantec's noise experts visited the START Lab to measure the existing sound levels of the facility. They completed 2 days' worth of measurements with and without the existing compressors operating. The study concluded that, with the proper mitigations, START⁺ will be able to meet any local noise ordinances. The local ordinance is in effect only overnight from 7 p.m. to 7 a.m. Monday through Friday, requiring 55 dBA at the residential property line, and operations close to 62 dBA outside those hours. However, the START Lab believes in being a good neighbor, given the proximity of the Lab to the neighborhood. The noise study (results in Figure 3) concluded that the START Lab is currently below the 62-dbA limit, and suggested some improvements to the existing facility infrastructure to further lower the noise so that the operation of START⁺ will not increase the sound levels. Figure 4 indicates additional measures that will be taken with the existing START Lab to further reduce the current noise footprint.

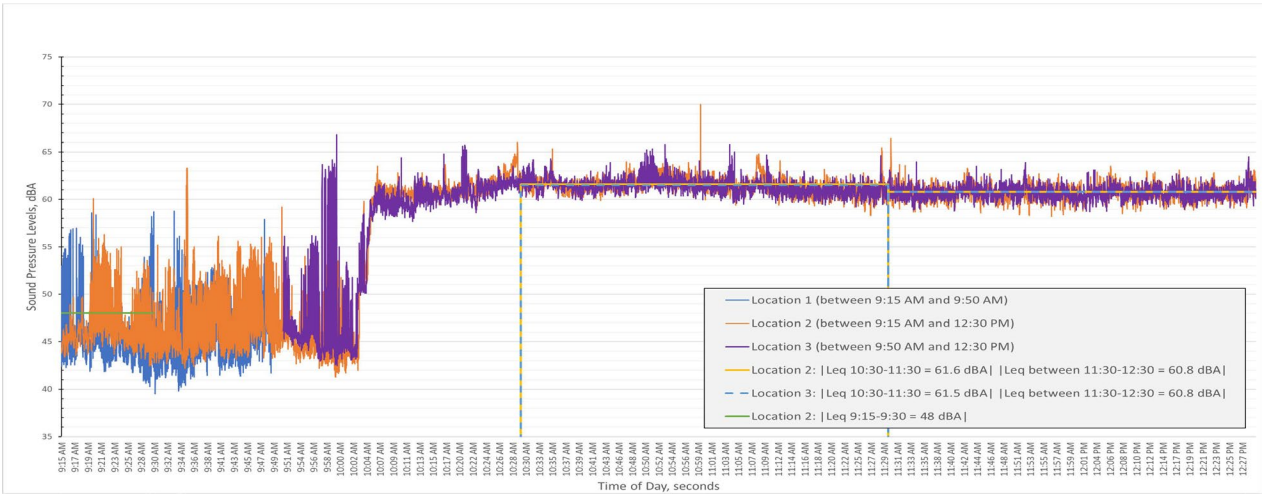

Figure 3. Existing START Lab sound levels.

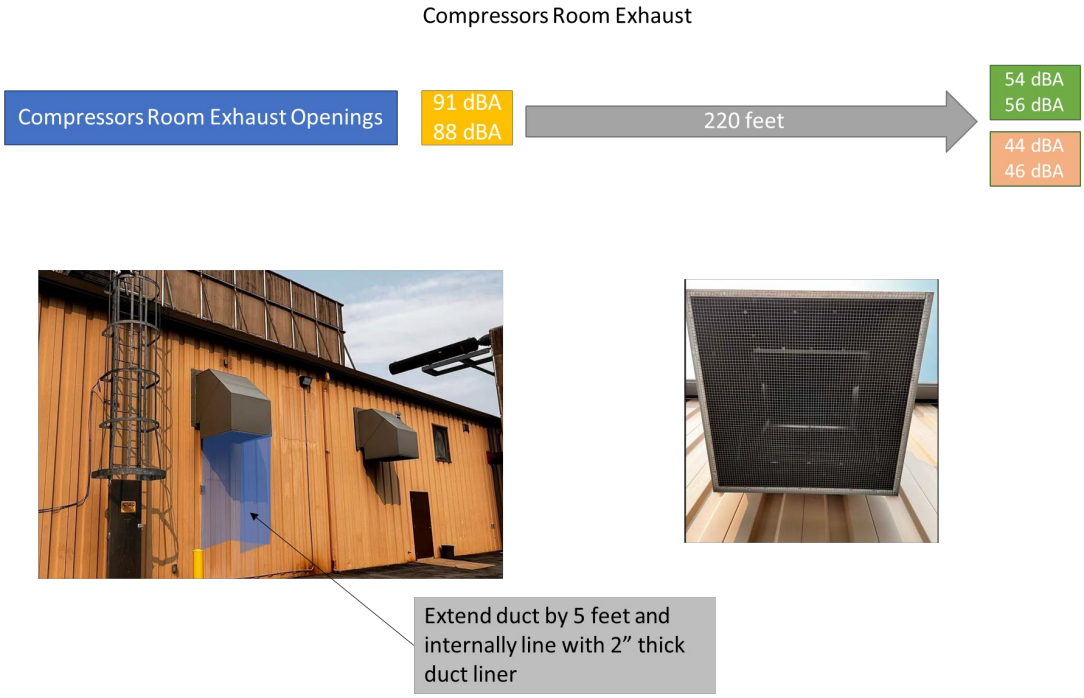

Figure 4. Suggested new mitigation strategy for existing START noise.

Task 4 – Mechanical Design

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Objective

The objective of Task 4 is to complete the mechanical design of the expanded facility, including the new compressors and two-stage turbine. During the first year, mechanical effort will be needed to ensure that the

architecture/civil/electrical/noise designs incorporate all design needs of the turbine. A third-party engineering firm will be used to create the mechanical design.

Research Approach

To help with the overall building design and the mechanical layout of START+, Penn State placed a purchase order with BMCD, a large engineering firm with past experience in designing turbine test facilities similar to START+. BMCD began designing the piping layout, heater, and motor generator designs.

Working with START personnel, BMCD selected CEL Aerospace to provide an initial proposal for dynamometer choices. CEL and BMCD have designed motor generators and water-brake dynamometers for other turbine test facilities of similar sizes; therefore, START personnel are confident in their success. The entire group, including START, BMCD, and CEL, met to discuss the different options available. On the basis of feedback provided in the meeting, START researchers agreed to refine the turbine drivetrain power and torque requirements to ensure that the new equipment system is sized properly. Another outcome of this study was the potential cost savings of using a water dynamometer. BMCD agreed to investigate other vendors for dynamometers to ensure that the lowest price is achieved.

BMCD and START personnel began discussions with vendors regarding the heater design for the new START+ rig. Process Combustion Corporation provided a rough order-of-magnitude proposal that met the START+ heating requirements. Their design (Figure 5) is a single-pass burner that achieves a 1,300 ˚F exit air temperature.

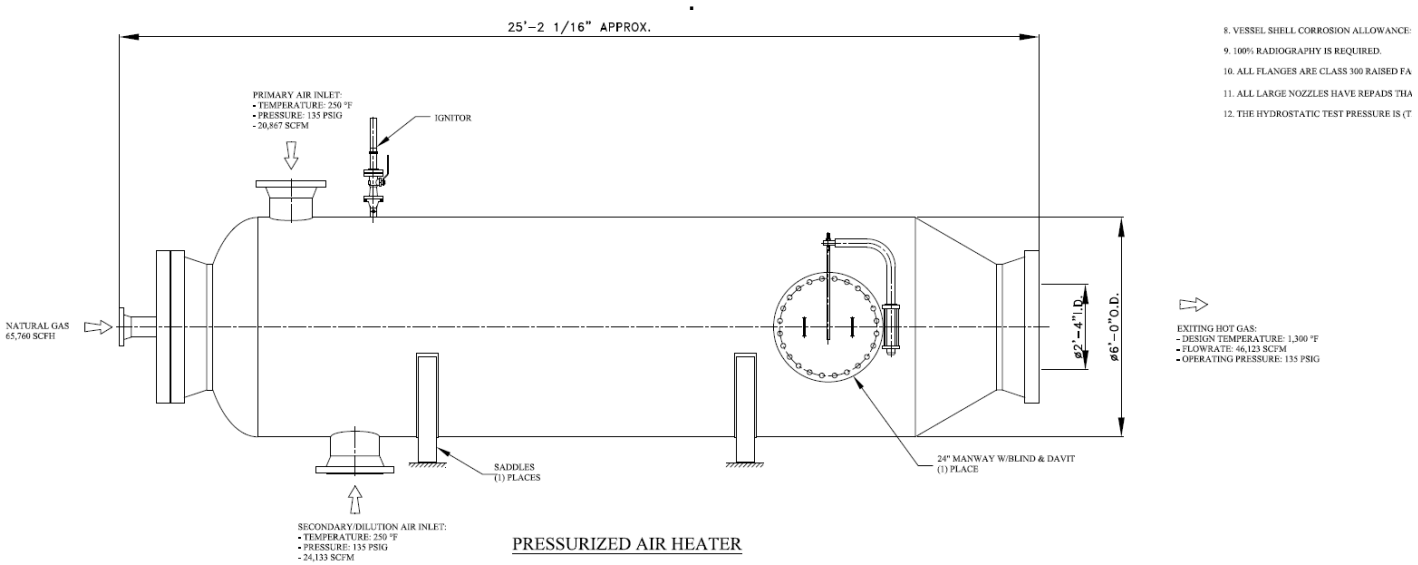

Figure 5. Process Combustion Corporation initial heater design for START+.

Task 5 – Procurement

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Objectives

Procurement of new compressors will be the crucial task in the first year. The compressors will set the electrical, facility, and mechanical design basis. After the compressors are ordered, and drawings are received, all aspects can move forward with the overall design of the facility.

Research Approach

The team created a request for quote (RFQ) document including all specifications for the compressors, motors, and auxiliary equipment. Two compressor vendors based in the United States have been selected to provide quotations for the program: Ingersoll Rand and FS-Elliott Company (FSE).

Ingersoll Rand submitted a proposal to supply four of their NX8000 compressors, each with a 2,250-horsepower motor. The Ingersoll Rand quote mostly met the START (RFQ) document requirements and required only slight revisions, primarily regarding the motor and controls. The compressors were able to meet the noise requirements.

FSE's initial proposal included four of their P700 compressors with 2,000-horsepower motors. However, their compressor cooling system did not meet the START Lab RFQ requirements and required significant revisions, particularly regarding noise. After the revisions were complete, FSE did increase the horsepower of each unit to 2,250 horsepower, to properly meet the discharge pressure requirement, and exceeded the noise requirements, by upgrading options for the silencers and motors.

The results of the West Penn Power study impacted the compressor quotations for the project. Because of the requirement for "soft" motor starters, Ingersoll Rand and FSE needed time to update their quotations from a variable frequency drive type of startup system.

Because both companies manufacture high-quality compressors, the selection process was difficult and lasted almost 8 months. After multiple rounds of questions and quotations, START personnel selected FSE because of their better pricing and the technical reasons presented in Table 1.

Table 1. Technical comparison between START+ compressor vendors.

Ingersoll Rand benefits	**FS-Elliott benefits**
Quick sales support response	Consistent with current units, experience, and steadiness
Overall number of compressors in the field	More economical fluid cooler design
Confidence in the inlet, oil cooler, and after-cooler setup	Higher air flowrate for same pressure
	Integration with current units
Ingersoll Rand weaknesses	**FS-Elliott weaknesses**
Concerns regarding flow pressure steadiness	Spare-part lead times
Number of fluid coolers required (IR 13 vs. FSE 7)	Concerns regarding after-coolers
Control system costs	

The principal factor in selecting the vendor was Ingersoll Rand's inability to ensure the air flow pressure steadiness that START+ requires at the compressor exit. On the basis of past experience with the existing START Lab, the FSE compressors can run consistently with a steady discharge pressure variation of less than or equal to 0.10-0.15 psi, which is critical for turbine research.

Task 6 – Construction

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Objectives

The Penn State execution plan will involve construction firms early in the design process to lower cost and improve the design, as part of Penn State's cost-sharing. By using an engineering and construction firm, the project will be able to start construction after the Pennsylvania Labor and Industry permit is received.

Research Approach

During work with Penn State OPP, a design-build method for the expansion was selected with the firm Alexander. Thus, the construction team onboarding was pushed to the beginning of the project. The design build method has been helpful, in

that it has allowed the team to see how inflation and costs have changed since the project was estimated. Unfortunately, Alexander was unable to keep to their budget. The START team is working with OPP to determine the best path forward to keep cost lower.

Milestones

Milestone	Completed or planned date
Building permit application submitted	May 31, 2024
Noise study completed	June 30, 2023
Compressor purchased	September 22, 2023
Contracts awarded for construction	April 25, 2023

Major Accomplishments

START selected the Alexander team to lead the design build process of START+ in April 2023.

The West Penn Power study was received in May 2023 and permitted the project to move forward.

The noise study was completed by Stantec Engineering in June 2023 and had a positive outcome. The new START+ laboratory expansion will be able to meet any local township noise ordinances with proper mitigations.

The purchase order was issued to FSE for the compressor engineering effort in September 2023. The compressors met all START Lab requirements and were less expensive than the alternative vendor, Ingersoll Rand.

Publications

A Penn State article about the program was released: https://news.engr.psu.edu/2023/thole-karen-start-lab-expansion.aspx

Outreach Efforts

A news article has been distributed about START+ publicly and shared with PA-15 Representative Glenn Thompson's staff. https://news.engr.psu.edu/2023/thole-karen-start-lab-expansion.aspx

Dr. Thole presented an update on the project to the combined CLEEN and Ascent community on May 4, 2023, at the FAA meeting. In addition, the START team presented the early designs to Pratt & Whitney, Solar Turbines, NASA, and other turbomachinery OEM's during Center of Excellence meetings.

Dr. Thole presented an update on the project to Boeing during a visit to the START Lab on August 16, 2023. Dr. Thole also presented to the National Academy's Aeronautics Engineering and Science Board on the planned START+ upgrades during the NASA University Leadership Initiative panel.

Finally, Dr. Thole delivered a keynote speech highlighting the program at the 2023 DOE UTSR conference at Penn State on October 30, 2023.

Awards

None.

Student Involvement

None.

Plans for Next Period

During the next period, START will oversee the new turbine rig design through strong collaborations with Pratt & Whitney. The team will work to select a turbine engineering firm by interviewing multiple candidates. START will create a request for quotations, review all bids, and select the firm that best meets the cost, schedule, and quality requirements of the program.

After issuing the award, the team will begin preliminary design by completing the rig layout, confirm with Pratt & Whitney the entire scope of the test turbine, generate a bill of material, plan material purchases with long lead times, and hold a review meeting to approve the design.

In addition, the START team will integrate the entire facility by having BMCD work with the building design firm to lay out piping, building penetrations, and supports, and ensure proper access for laboratory personnel. BMCD, with START personnel, will design a motor generator to dissipate the turbine power, while exploring additional capabilities. The team will create a request for quotation, review all bids, and select the company that best meets the cost, schedule, and quality requirements of the program. The group will collaborate with the selected vendor to develop manufacturing drawings so that the turbine rig layout can be completed.

The START team will order remaining air compressor components and complete manufacturing. This process will include reviewing manufacturing quality documents, such as the compressor starter, starter layout, fluid cooler general arrangement drawings, and manufacturing reports; resolving instances of non-conformance; and approving final inspection reports. START representatives will attend factory performance testing and ensure that the compressors meet all quoted performance metrics, and will review testing data, such as hydrotests, flow, and pressure results. After the compressors are complete, the START team will oversee installation of equipment in START+ to ensure that the compressors fit on their anchor bolts and are grouted into place, per the compressor vendor's requirements, and that all lifting requirements are met.

The START and OPP teams will continue to attend weekly construction review meetings to ensure that the schedule and budget remain within the plan. START will help solve any issues as they arise between the contractor and Penn State's OPP, and facilitate planning installation between the contractor and equipment vendors. The team will review quality documents to verify that all drawings and standards by the construction firm are maintained, and will conduct walkthrough inspections with the design firm to ensure that drawing requirements and tolerances are within specifications.